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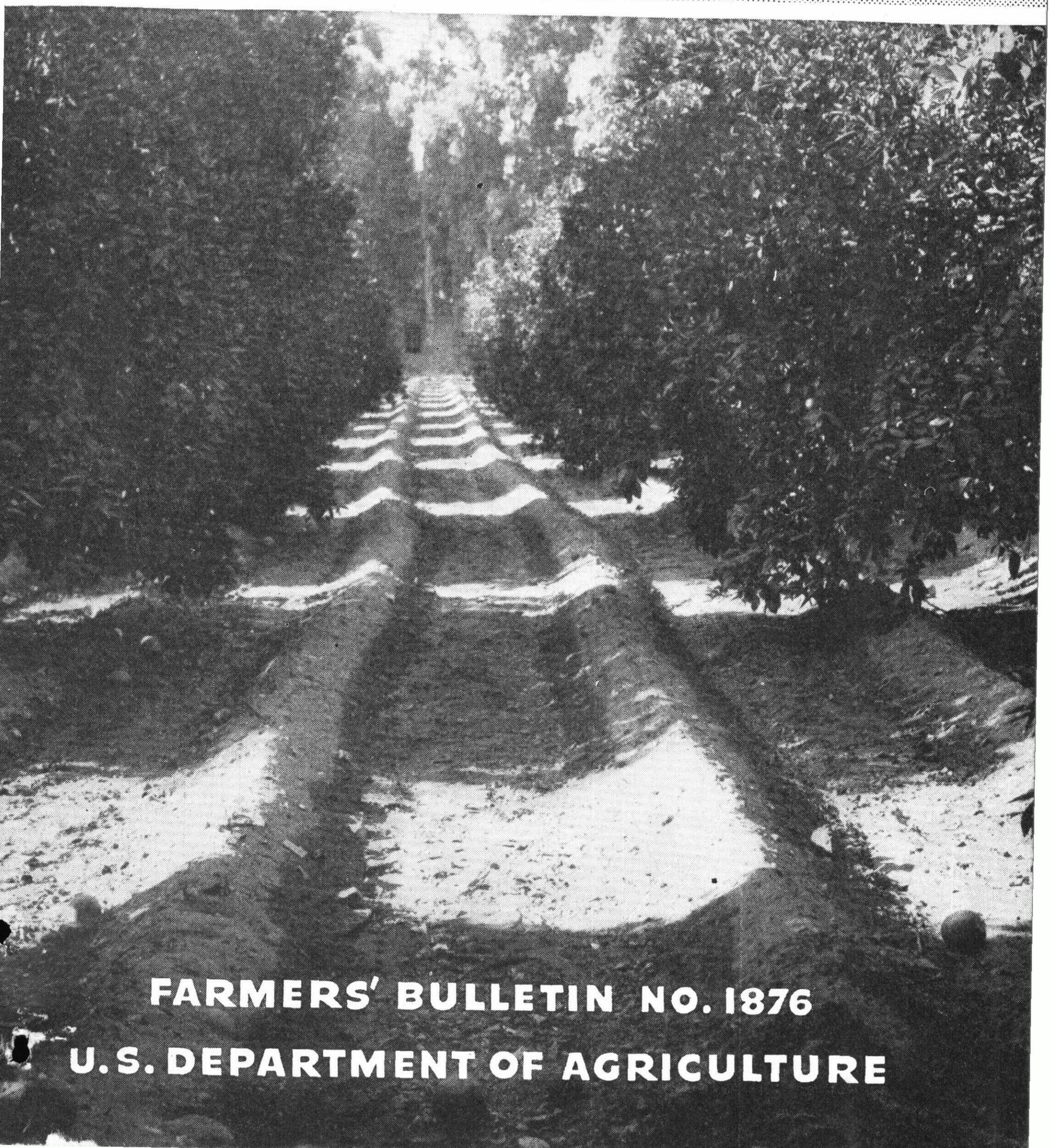
Irrigation Problems in CITRUS ORCHARDS



FARMERS' BULLETIN NO. 1876

U. S. DEPARTMENT OF AGRICULTURE

SOME ORCHARDISTS in Los Angeles and San Bernardino Counties, Calif., have consistently obtained high yields from their citrus orchards with the application of relatively small amounts of irrigation water, whereas others who use a greater amount of water have harvested less fruit. This fact suggests that all growers are not making the most effective use of the supply of irrigation water.

This bulletin reports a study of irrigation practices and yields in orchards in Los Angeles and San Bernardino Counties and recommends certain improvements in methods of cultivation that will make for better use of water. Because conditions are similar in other areas it is believed that many orchardists will profit from the discussion of the California studies and find use for the improvements in irrigation practices that are suggested.

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IRRIGATION PROBLEMS IN CITRUS ORCHARDS

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INTRODUCTION

HOW MUCH WATER is needed to irrigate a citrus orchard? An answer cannot be given to the question put in this way, but facts are in hand that show irrigators to be using more water in their orchards than would be needed under improved irrigation practices. Large expenditures have been made in developing necessary water supplies and delivering them to orchard units with the minimum loss in transit. Further economies rest largely with those who apply the water to the land.

Growers can make better use of irrigation water if they understand how the water is used by orchard trees, the effect of seasonal weather conditions, and the differences in soils that make it necessary to use different irrigation practices in different orchards to maintain a satisfactory supply of available soil moisture. To give growers some of the information they need to make more effective use of their water supply, the records of a large number of orchards in Los Angeles and San Bernardino Counties are discussed in this bulletin, and recommendations are made for improving irrigation practices and reducing the cost of irrigation.

CLIMATE AND THE AMOUNT OF WATER USED BY CITRUS TREES

The amount of water extracted from the soil by roots of citrus trees and used in the trees or lost by transpiration from the leaves can be measured. If the amount so used in an orchard from month to month

[1] In December 1938 the duty of conducting experiments and demonstrations in connection with the construction and hydrologic phases of farm irrigation and land drainage (formerly a function of the Bureau of Agricultural Engineering) was assigned by the Secretary of Agriculture to the Soil Conservation Service; and the duty of conducting investigations, experiments, and demonstrations in connection with crop production on irrigable lands, the quality of irrigation water and its use by crops, and methods of improving and maintaining the productivity of irrigated soils was assigned to the Bureau of Plant Industry.
The investigations in irrigation reported in this bulletin were conducted by the Division of Irrigation and Drainage of the Bureau of Agricultural Engineering before October 1938; later the author was transferred to the Soil Conservation Service.

is recorded and compared with the maximum temperatures for the same period, it will be seen that more water is used by trees when temperatures are higher, just as more water is evaporated from water surfaces under higher temperatures. This use of water in the trees and the loss through the leaves is termed "transpiration use" of water.

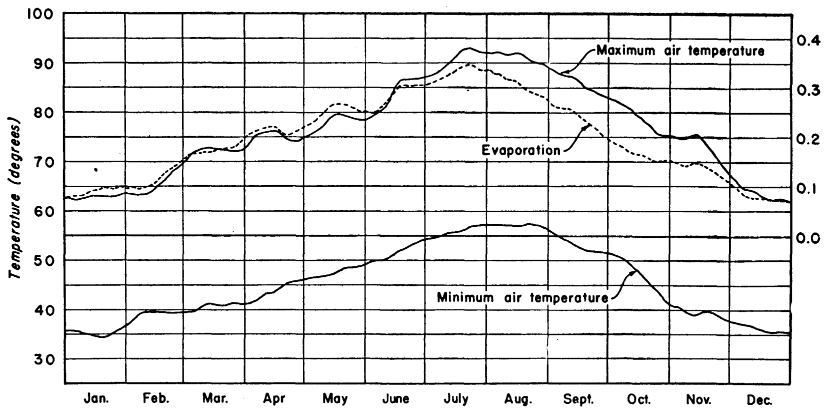

FIGURE 1.—Average maximum and minimum temperatures and average evaporation from a free water surface in a shallow black pan for the 5 years 1932–36, Pomona, Calif.

If the records of temperature, evaporation, and transpiration-use of water for a given period are represented graphically, as in figures 1 and 2, it can be seen that the lines that represent transpiration-use of water follow closely the lines that represent maximum temperatures and evaporation from a free water surface. More specifically, it has

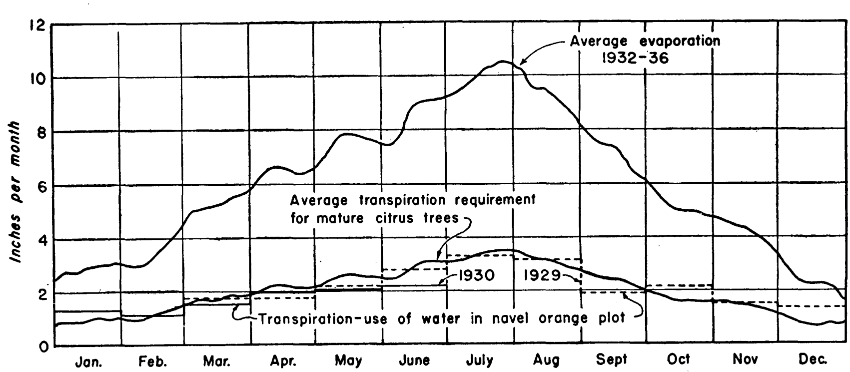

FIGURE 2.—Evaporation from a free water surface and transpiration-use of water by mature citrus trees in eastern Los Angeles County, Calif.

been found that in a mature citrus orchard the average transpiration-use of water is one-third of the evaporation from a free water surface.

In figure 2 the values for transpiration-use are expressed in a unit equivalent to that in which evaporation is recorded, inches per month. For an orchard area transpiration-use is expressed as the equivalent depth of water in inches over the area. In this chart the values plotted in the solid continuous line are averages. The

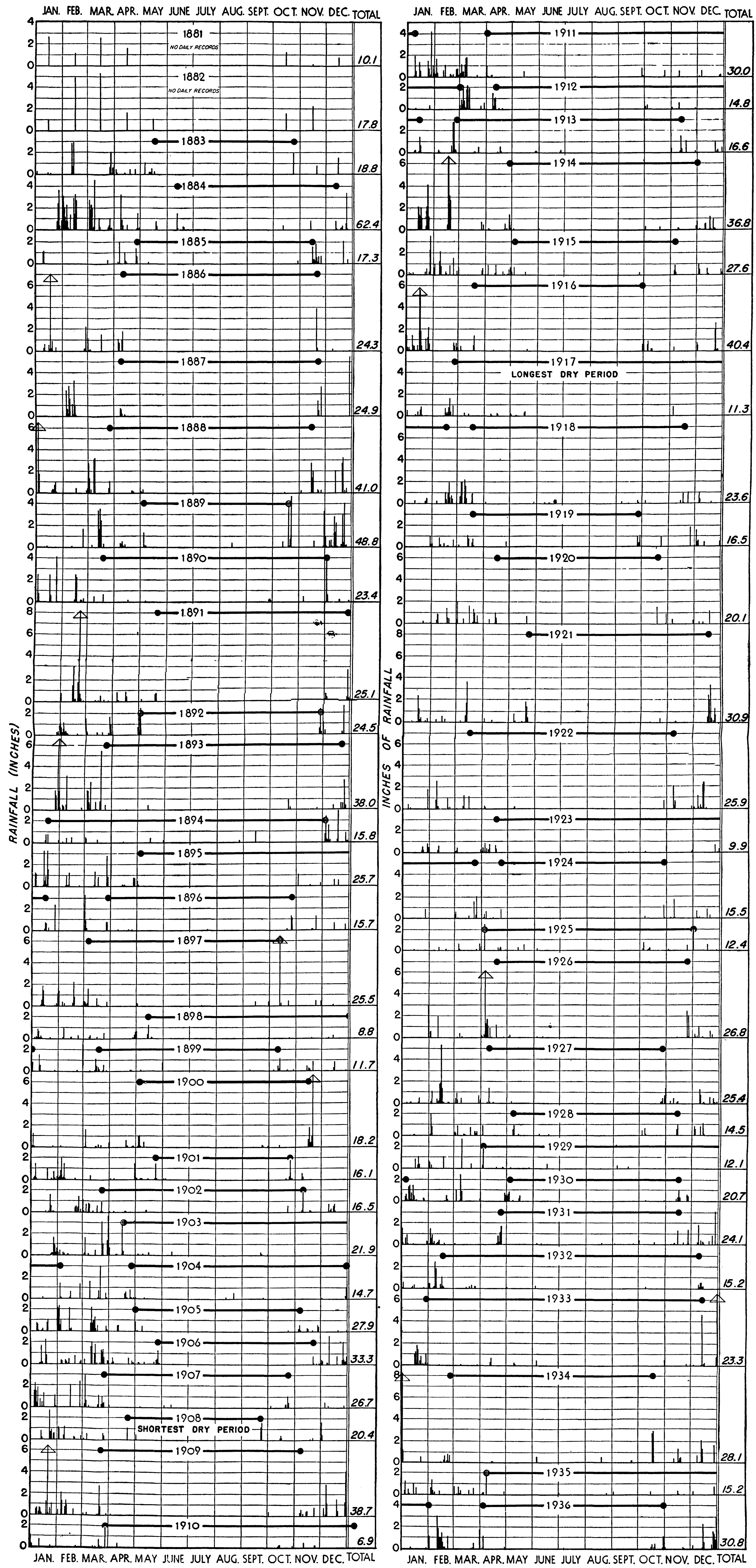

FIGURE 3.—Rainfall at Glendora, Calif., 1881–1936. The heavy horizontal lines show the length of the irrigation seasons.

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total annual evaporation, 72 inches, is three times the annual transpiration-use of mature citrus trees, 24 inches, in the area where these studies were made. (Losses by evaporation from the ground surface and use of water by cover crops are not included in this value.) The variation in transpiration-use of water for a certain plot of mature navel orange trees March 1929 to June 1930 is also shown.

HOW CLIMATIC RECORDS ARE PUT TO USE IN DETERMINING THE AMOUNT OF WATER NEEDED BY CITRUS TREES

During the winter months moisture from rainfall may be expected to take care of the needs of the trees. The average rainy season begins late in November and lasts a little more than 4 months. Seasonal variations in rainfall at Glendora, Calif., are shown in figure 3. Ordinarily the soil is filled to field capacity at the time of the last effective spring rain, and when the supply of moisture has been depleted, irrigation must be relied on until the next effective rain in the fall. The period between the last effective spring rain and the first effective fall rain is shown for the years 1883–1936 in figure 3.[2] The average for the 55 years 1883–1937 [3] is 232 days.

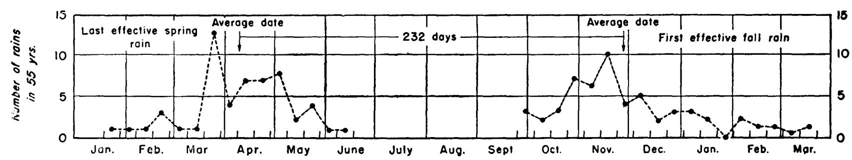

FIGURE 4.—Average date of last effective spring rain and first effective fall rain for the 55 years 1883–1937.

A study of figure 3 reveals that usually the rainy season ends between March 10 and May 10, the average date being April 9. Extremes occurred in 1884 and 1894. In 1884 the rainy season ended June 12; in 1894, January 18. These variations are brought out graphically in figure 4.

The first effective fall rain came during the last week in September in 3 years of the 55, but there were years when no effective rains fell until February or March. November 27 was the average date for the first effective fall rain. From a study of figure 4 it may be determined that the chance is only about 1 in 4 that rain will fall in sufficient amount to end the irrigation season before November 1. Distribution of fall rains is so variable that the odds are against the grower who defers irrigating and gambles on the occurrence of rain. Therefore, regular irrigation should be continued each year until effective rains have fallen.

During each of the 55 dry periods shown in figure 4, variations in the total seasonal evaporation were recorded. Most dry seasons were found to lie within the range of evaporation between 50 and 60 inches. The average for all seasons was 55 inches. One-third of this value, 18 inches, represents the average seasonal transpiration

[2] The terms "last effective spring rain" and "first effective fall rain" cannot be defined with precision. The aim has been to get some measure of the length of the dry season. The time of the last spring rain during which the soil was filled with moisture to about its field capacity was used as the time of the last effective spring rain. Rain in amount sufficient to terminate the regular irrigation season was considered as the first effective fall rain. The term "field capacity" designates a soil moisture ordinarily found within a few days after rain or irrigation has thoroughly moistened the soil and rapid drainage has ceased.

[3] The data shown in figure 4 include an additional year.

requirement for mature citrus trees during the dry season. Not all this 18-inch transpiration requirement need come from irrigation, since a certain amount of storage holds over from winter rains. This storage may be equivalent to 3 inches on the more sandy soil or as much as 5 inches on the deep medium sandy loams, depending on the root distribution, the soil, and the cover-cropping practices. The problem of the grower is to keep an adequate supply of moisture within the root zone during the summer months after this stored rainfall has been used.

After the trees have used the 3 to 5 inches of moisture stored in the soil from winter rains, further withdrawals must come from the supply made available through irrigation. For mature trees, the equivalent of from 13 to 15 inches of water must be supplied by irrigation.

THE SPREAD BETWEEN THE AMOUNT OF WATER USED BY TREES AND THE AMOUNT APPLIED BY IRRIGATION

To place 13 to 15 inches of moisture within the root zone during the course of an irrigation season many growers find it necessary to apply as much as 26 inches of water or more on the ground surface. Certain losses by evaporation are unavoidable, and run-off and percolation below the root zone also occur. Efficient irrigators reduce these losses to a minimum. Others, less successful, apply much water that either runs off or percolates below the root zone. Hence, relative efficiencies of different irrigation practices, as well as differences in the needs of the trees, affect the results obtained from the application of irrigation water. The goal of irrigators should be the maximum fruit production and a minimum spread between the amount of water used by the trees and the amount of water applied.

USE OF WATER AND YIELD OF FRUIT

Records of two of the mutual irrigation companies serving 5,000 acres of citrus orchards in the eastern part of Los Angeles County were examined to determine whether there is a relation between the amount of water used and the yield of fruit in these orchards. The analysis included records of all accounts for which complete 6-year data are available. Practically all the orchards are mature, the age of most of the trees being between 20 and 50 years.

In the area included in the study are many mixed plantings of oranges and lemons, and there is no material difference in cultural practices for these crops. The average navel orange yield per tree was slightly higher than the average lemon yield, and the average Valencia yield somewhat lower than the average lemon yield. But for the purposes of this study all varieties were included, and no separations were made.

Production records were obtained for 46,630 navel orange trees, 32,420 Valencia orange trees, and 29,850 lemon trees. For all orchards the average annual production for the 6-year period 1931–36 was compared with the average annual amount of irrigation water applied during the period. These records represent the practical experience of farmers in this area and give a measure of the success they have had in the business of producing citrus fruits.

Orchards were grouped according to yield as follows: (1) 1 up to 3 field boxes per tree, (2) 3 up to 5 field boxes per tree, (3) 5 up to 7 field boxes per tree, and (4) 7 field boxes per tree or more.[4] The number of orchards in each group is shown graphically in figure 5.

There is a wide range in the amounts of water used by each group, but the averages are progressively higher for the orchards with higher yields. The average amount of water used by the marginal group, with lowest yields, was 20.1 inches per year, whereas for the group with the highest yields it was 25.7 inches per year. Relatively few orchards yielded 7 or more field boxes per tree, but it is worthy of note that some growers obtained this production with remarkably little water.

The variations in yield correlative with the variations in amount of water used can also be shown by grouping the orchards according to the amount of water applied. This grouping is shown in figure 6. In this chart the orchards falling within the different water-use groups are classified according to yield. The average yield for each group is shown, and the points indicating the averages are connected by a line. The line slopes to the right, in the direction of higher yields, and then back to the left. The curve, of course, would be expected to take this form, since the yield would not continue to increase indefinitely with the application of greater and greater amounts of water.

The growers applying more than 28 inches of water per year have not done so well as the more conservative irrigators. The difference in average yield between groups 4 and 5, however, is slight. In the next group the average yield falls sufficiently to make a decided change in the direction of the line that indicates yield.

The greatest number of growers used from 20 to 24 inches of water per year. The average yield of their orchards is not so great as the yield obtained with 24 to 28 inches of water.

In considering these average yields it should be noted that though the averages for groups 3, 4, and 5 differ, the range in yield for all these groups is nearly the same. The differences between the average yields for the several groups is much less than the difference between yields within any one group.

In the course of field observations on heavily irrigated orchards, root distribution has been observed by the writer in trenches that were dug across irrigation furrows. Where excessive water had been applied on coarse soils, very few roots were found in the soil under the furrows. More feeder roots were observed in the soil where the water had moved out laterally from the furrows toward the dry-tree line. The soil directly under the furrows, which had been leached by excessive irrigation, did not offer the most favorable conditions for root growth. Orchards receiving excessive irrigation lose the nitrogen carried beyond the reach of tree roots, and the cost of irrigation is, of course, greater than it need be.

In the area covered in this study the average annual use of 26 inches of irrigation water on mature orchards over the period 1931–36 represents an efficiency of about 60 to 65 percent in the application of water. The remaining 35 to 40 percent must have been lost by evaporation, run-off, and percolation below the root zone. A reduction of these losses might be effected, judging from the fact that some

[4] The weight of fruit in one field box at the packing houses through which most of the fruit was shipped was as follows: Lemons, 48 pounds; navel oranges, 52 pounds; Valencia oranges, 55 pounds. For orchards with average tree spacing in this area, a yield of 7 field boxes per tree is equivalent to approximately 600 field boxes per acre, or 400 packed boxes per acre.

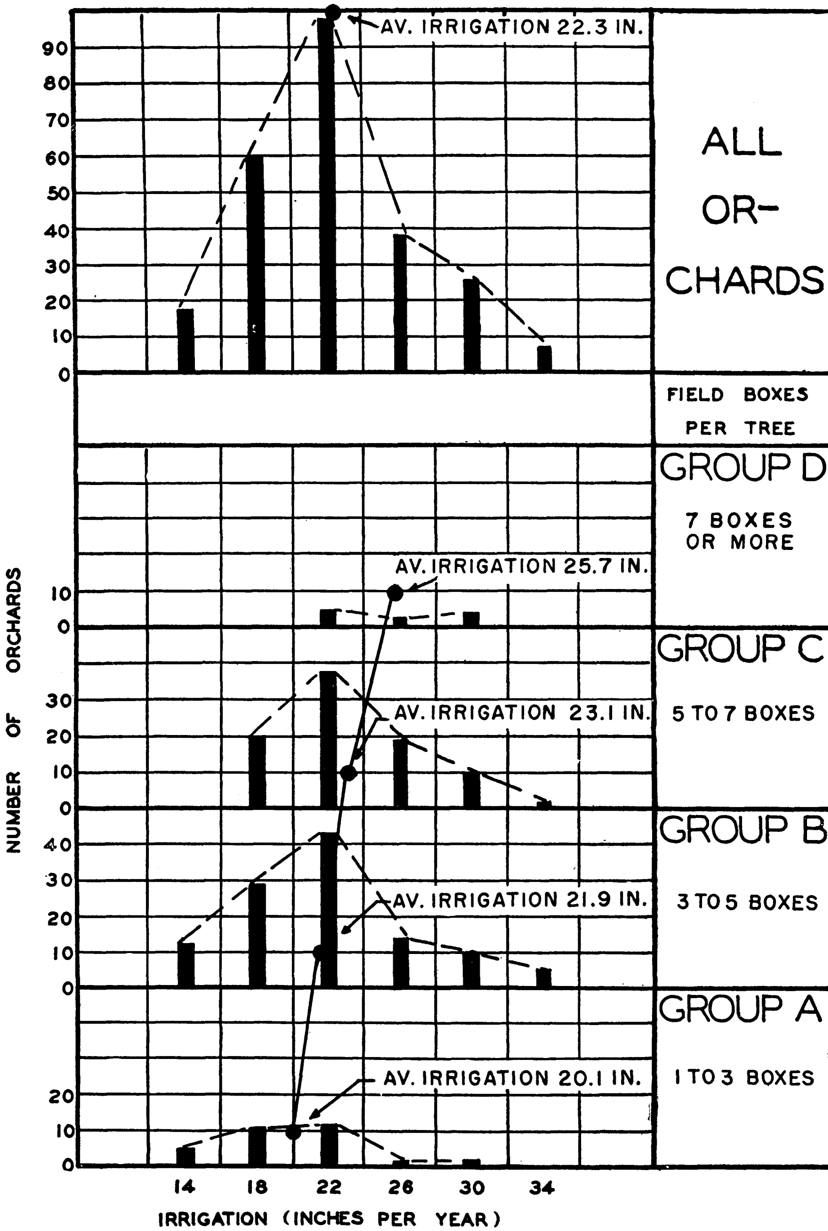

FIGURE 5.—Amount of water used by orchards grouped according to yields. The height of the bars indicates the number of orchards.

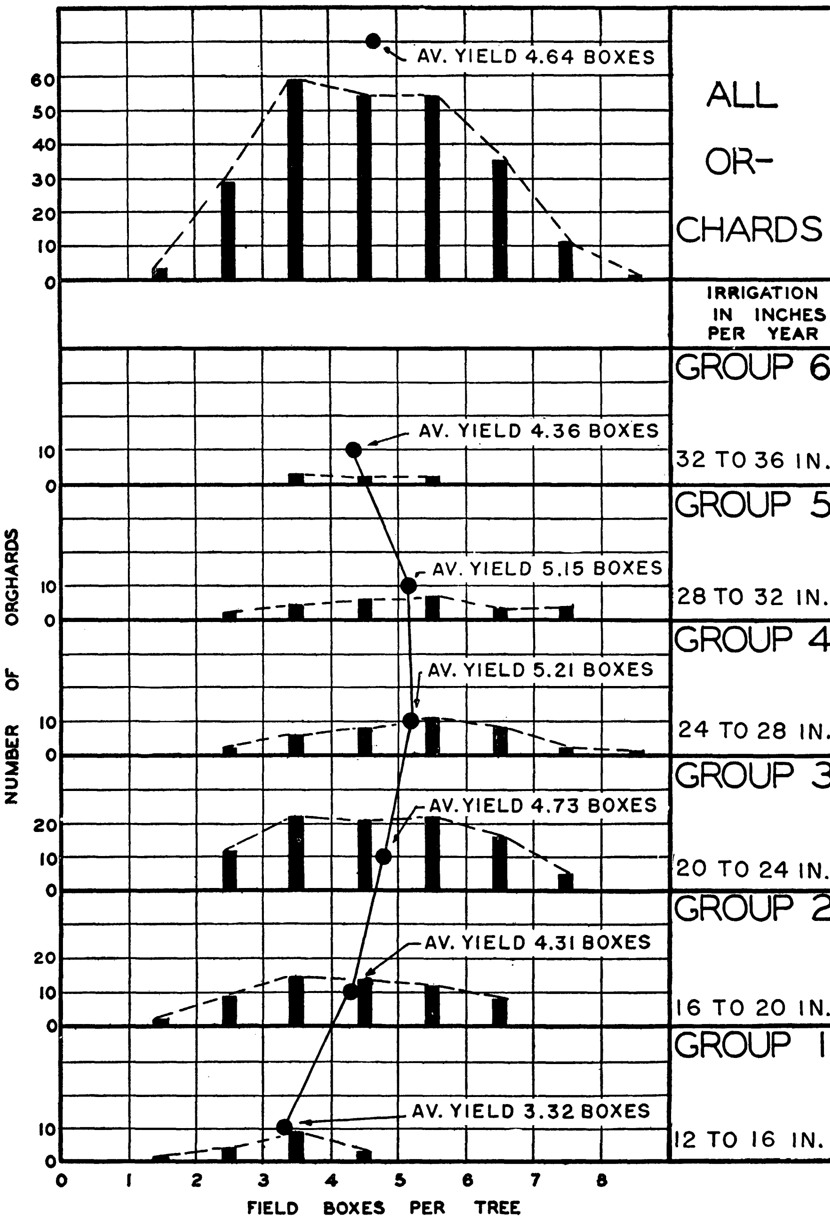

FIGURE 6.—Yields of orchards grouped according to amount of water used. The height of the bars indicates the number of orchards.

growers with the use of less water get yields as high as those who use 24 to 28 inches. Apparently there is ample opportunity for improvements in methods of application.

YIELDS AND QUANTITY OF WATER USED IN ORCHARDS ON SOILS OF DIFFERENT TEXTURE

All orchardists have observed that trees respond differently to identical amounts of irrigation on different soils. The explanation, at least in part, lies in the fact that irrigation and other cultural operations may be performed more efficiently on certain soils than on others. Coarse-textured soils require more frequent irrigations than the fine-textured soils, and they lose more water by percolation below the root zone. Hence, the prevention of losses of plant nutrients by leaching may be a serious problem on coarse soils.

Water penetrates slowly through soils having compact subsoils, and deep percolation losses are less. Penetration, however, may be so slow that water may be lost as run-off. On such soils loss of the more fertile topsoil will be greater than on the more porous soils. The loss of soil carried away by the irrigation water will also be greater.

In medium-textured soils having deep uniform profiles, trees usually root deeper, and proper irrigation is much easier.

Irrigation and yield were studied for orchards on soils of three different textures in the San Dimas area. In table 1 the amount of irrigation water applied each year on these orchards and the corresponding yields are given. More water was applied to orchards on the porous soil north of Red Hill, but yields were not appreciably different from those for orchards on the more compact Red Hill land. Neither of these two groups of orchards yielded as well as the orchards south of Red Hill, where the soil is a deep sandy loam and fine sandy loam. The highest average production, 5.7 field boxes per tree, was obtained from the orchards on these deeper soils. Orchards on Red Hill yielded 4.2 field boxes per tree; those north of Red Hill, 4.1. The yield on the deep soils of medium texture is well above that on the other soils.

The variation in root systems of apparently similar trees in soils of different textures is shown in figure 7. The tree with the more extensive root system in a deep soil (fig. 7, *A*) obviously has had a large reservoir from which to draw soil moisture. The tree shown in figure 7, *B*, with its smaller root system in a coarse soil of low water-holding capacity, has had a rather limited reservoir of soil moisture. The time elapsing between irrigations for orchards on soils represented in 7, *B* will be much shorter than that for orchards on the kind of soil represented in 7, *A*.

TABLE 1.—*Amount of water applied to citrus orchards on soils of three different textures and yields from these orchards, San Dimas area, 1931–36*

Location	Accounts	Soil texture	Average yield per tree	Average water applied per year
	Number		*Fieldboxes*	*Inches*
North of Red Hill	39	Recent gravelly sandy loams in San Dimas wash area.	4.1	25.2
Red Hill	40	Older weathered alluvial soil with compact subsoil.	4.2	18.1
South of Red Hill	39	Deep uniform sandy loams and fine sandy loams of intermediate age.	5.7	23.3

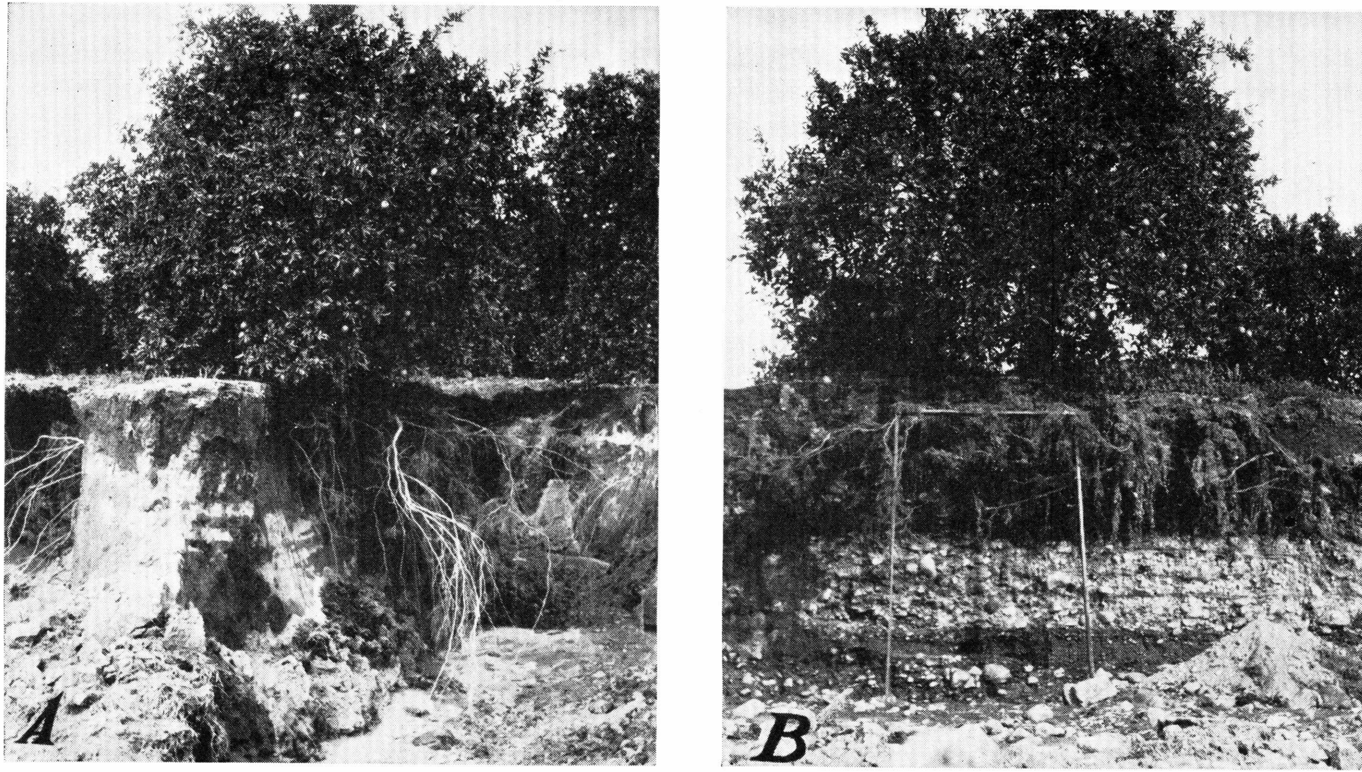

FIGURE 7.—Valencia orange trees: *A*, In a deep uniform fine sandy loam, with roots at a depth of 9 feet; *B*, in a stony sandy loam, with roots concentrated in the upper 3 feet of soil.

INTERVALS BETWEEN IRRIGATIONS

Variations in soils and root systems bring up problems in the distribution of water over the district served by an irrigation company. A fixed irrigation schedule, such as some companies have used in the past, leaves much to be desired if the irrigation needs of different orchards vary widely and no choice of intervals is offered. On the other hand, while a system whereby water can be delivered on demand to any point in the district might be the most desirable, under existing conditions it may be neither practical nor economical to make the necessary changes.

The schedules for water delivery of most companies have been established to meet the needs of early practices. How well do these schedules meet present water requirements of the orchards served? A survey was made during 1936 of orchards in eastern Los Angeles County to gather data on the relation of irrigation intervals to water deficits in the trees.

In judging the results of such surveys, it should be remembered that from present knowledge the best interval between irrigations for a given orchard cannot be established with any degree of exactness. Further study is needed before any limits can be set up for permissible water deficits in the trees, for the extent to which it is desirable to dry out the soil, or for the proportion of the root zone that needs to be irrigated. All these have a bearing on the problem of setting up irrigation schedules.

The influence of soil type on root distribution was brought out in the discussion of figure 7. Where the roots extend to a great depth and are rather sparsely distributed, water deficits in the trees build up gradually as time from irrigation increases, and the interval might be varied considerably without serious risk. Where the roots are concentrated within a shallow zone, water deficits in the trees may become extreme within a period of 4 or 5 days, and there are more chances of serious water shortage. The need is to determine which orchards are most sensitive to water shortage and plan to make irrigation schedules flexible enough to take care of them.

WATER DEFICITS

How well does a given schedule fit the needs of any particular orchard? To answer that question it is necessary to determine the water deficits that are developed in the trees. The deficits may be ascertained readily from fruit measurements. A regular series of early-morning measurements will show how the fruit and the trees are responding to the available moisture supply. If the rate of fruit growth decreases materially before each irrigation and rises after irrigation, positive evidence is obtained of water deficits occurring under current practices.

Measurements must be made in the early morning because daily shrinkage may be measurable within 2 hours after sunrise. Select two fruits on the north or west side of a tree, away from the early morning sun. Smooth green fruit at least 10 centimeters in circumference at about eye level or lower can be more accurately measured than rough irregular fruits. If rough or irregular fruit is chosen, mark the fruit with india ink by placing a piece of coarse thread dipped in ink along the upper side of a rubber band placed around the

fruit. When the ink is dry, remove the rubber band and make all measurements with the tape set on this ink line. The marking with ink should be done when the fruit is dry.

It is advisable to use a small flexible steel tape graduated in centimeters. Loop the tape around the fruit at its largest diameter, holding the tape snugly but not tightly enough to compress the fruit.

The measurements should be recorded in tabular form for comparison with measurements made on the preceding day. Plotted records, however, are easier to follow. The volume of the fruit should be plotted. The measurements of volume are obtained by converting circumference measurements to volume or by using a plotting scale properly graduated so that the conversion is automatically taken care of.

In the study reported here 30 trees were checked on each 10-acre block in 74 orchards in 1936. The majority of the orchards (table 2) have moderate to high water deficits before irrigations, particularly during the late summer months. August and September give irrigation schedules their most critical test because transpiration requirements are high at that time, and the moisture supply must come entirely from irrigation. Under a system in which trees in most of the orchards develop moderate to high water deficits on present schedules there could be little advantage to the district as a whole in changing to a demand system of water delivery though there might be real advantages to certain individual orchardists. It would appear to be adequate if enough schedules were maintained whereby water might be delivered at regular intervals but often enough to take care of the orchards requiring the most frequent irrigations.

TABLE 2.—*Intervals between irrigations, amounts of water applied at each irrigation, and water deficits in 74 orchards in eastern Los Angeles County, Calif., 1936*

Orchard No.	Soil texture	Interval between irrigations	Amount of water per acre applied at each irrigation	Water deficits					
				May	June	July	August	September	October
		Days	*Acre-inches*						
1	Clay loam	60	5.7			Moderate	Moderate	Moderate	
2	Gravelly sandy loam	45	5.0						Moderate.
3	Clay loam	35	4.0		Moderate	Moderate	Moderate	Moderate	Do.
4	Loam	35	4.0					Slight	Slight.
5	do	31	3.2					Moderate	
6	Clay loam	30	2.9	Moderate	Moderate	Moderate	Moderate	do	
7	Loam	30	5.4			Extreme	Extreme	Extreme	Moderate.
8	Sandy loam	30	3.5		High	High	High	Moderate	Do.
9	Loam	30	2.9		None	None	None	None	
10	do	30	3.1				Moderate	Extreme	Extreme.
11	do	30	3.6						Moderate.
12	Sandy loam	30	3.3					Moderate	High.
13	do	30	3.3	None	None	Moderate	Moderate		
14	do	30	4.3						Moderate.
15	Gravelly sandy loam	30	3.1						Do.
16	Stony sandy loam	30	2.4	Moderate	High	High	High		
17	Fine sandy loam	30	3.3				Extreme	Extreme	Extreme.
18	Loam	30	2.6					do	Do.
19	Gravelly sandy loam	30	3.7					Moderate	Moderate.
20	Sandy loam	30	4.4					do	High.
21	Gravelly sandy loam	30	2.6					High	Do.
22	do	30	2.9					Extreme	Do.
23	do	30	3.6					Moderate	Moderate.
24	Loam	30	2.2	Slight	Moderate	Moderate	Moderate		
25	do	30	2.2	do	Slight	Slight	Slight	Slight	
26	Gravelly sandy loam	30	4.1					do	Slight.
27	do	30	4.5					Moderate	Moderate.
28	Clay loam	30	4.0	Slight	Slight	Slight	Slight	High	
29	Fine sandy loam	30	2.7					do	
30	Sandy loam	30	4.0		Slight	Slight	Moderate		
31	Loam	30	3.2					Moderate	Moderate.
32	Gravelly sandy loam	30		Moderate	Moderate	Moderate	Moderate		
33	Sandy loam	30	4.1					Slight	Slight.
34	Loam	30				High	High	High	Moderate.
35	do	30	4.0	None	None	Moderate	Moderate	Moderate	
36	Gravelly sandy loam	30						High	High.
37	Sandy loam	30	3.4					Moderate	Moderate.
38	do	30	3.4				Moderate	High	
39	Gravelly sandy loam	30	3.2					Moderate	Moderate.
40	Loam	30	2.5					Extreme	Do.

41	do	30	2.5					High	Do.
42	do	30			Slight	Slight	Moderate	Moderate	High.
43	Gravelly sandy loam	30	3.2						Moderate.
44	do	30	4.3					High	
45	Sandy loam	30	3.8				High	do	High.
46	do	30	3.8			Extreme	do	do	Moderate.
47	do	30	1.9			do	Extreme	Extreme	Extreme.
48	do	30	4.0					Slight	Slight.
49	Gravelly sandy loam	28	4.9	Moderate	Moderate	High	High	High	
50	Stony sandy loam	26			do	do	do	Moderate	
51	do	25	3.2	Slight	Slight	Moderate	do		
52	Sandy loam	22	3.4					Moderate	Moderate.
53	Stony sandy loam	22	1.7	Moderate	Moderate	High	High		
54	Gravelly sandy loam	22	2.9						Moderate.
55	Clay loam	21	4.0					High	Do.
56	Sandy loam	21	2.3			Moderate	Moderate	Moderate	Do.
57	Stony sandy loam	20	2.5	Moderate	High	High	High	High	
58	Gravelly sandy loam	20		None	None	Moderate	Moderate	do	
59	do	20	2.7	High	Extreme	Extreme	Extreme		
60	do	20	2.9						Moderate.
61	Stony sandy loam	20	2.6	Moderate	High	Extreme	Extreme		
62	Sandy loam	20	1.8			High	High	Extreme	Extreme.
63	Gravelly sandy loam	15	2.3		Moderate	do	Extreme	do	
64	do	15	3.4			Slight	Slight	Slight	Slight.
65	Sandy loam	15					Moderate	Moderate	Moderate.
66	Stony sandy loam	15		None	Moderate	Moderate	do	do	
67	Gravelly sandy loam	15	3.5	Moderate	do	High	High	High	
68	do	15	4.0			Moderate	do	Moderate	
69	do	15	4.0			do	Moderate	do	
70	Loam	15	1.8			High	High	High	Moderate.
71	Sandy loam	15	2.2			Moderate	Moderate	Moderate	Do.
72	Gravelly sandy loam	15	3.3					Slight	Slight.
73	Stony sandy loam	10	.7	Slight	Slight	High	High	High	
74	Light gravelly sandy loam	10	1.4	None	do	Slight	Slight	Slight	

SUGGESTED SCHEDULE

A choice of schedules based on the period of maximum demand (June 15 to October 1) might be offered. These schedules might have primary intervals of 10, 15, 20, or 30 days, and a selection from these should be adequate to meet the needs of most orchards. Under a system of this type each grower has the privilege of selecting the service desired at the beginning of each season, but must follow the selected schedule throughout that season. During the more moderate weather, before June 15 and after October 1, the interval may be lengthened since less water is required by the trees. Delivery on demand may be used whenever the distributing lines are not operating at full capacity.

Schedules worked out in this manner for the average season are shown in figure 8. Midsummer intervals are fixed on 10-, 15-, 20-, and

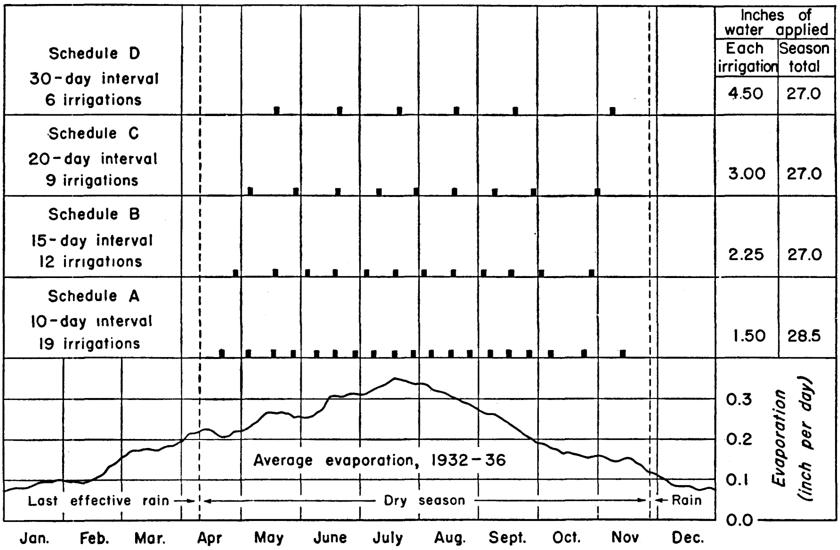

FIGURE 8.—Typical irrigation schedules, with water furnished on selected schedule during the average dry season and on demand during the remainder of the year.

30-day schedules. The proportionate increases in intervals that may be used for early-spring and late-fall irrigations have been established from evaporation records.

A current record of evaporation from a shallow-black-pan evaporimeter showing the total cumulative evaporation since the last date of irrigation gives an excellent measure of the opportunity for transpiration and hence of the probable needs for irrigation. This method is now being used in some situations and is a valuable aid in predicting irrigation needs.

Having once selected a schedule that appears suitable for a particular orchard, the grower still has an opportunity to vary the amount of water applied by using more or less water at an irrigation. In the future, it may become possible to establish the most desirable interval for each orchard more precisely than can be done with present-day methods. However, even after precise limits for permissible degrees

of water deficit in the trees have been established, various factors will operate to limit the attainment of an ideal interval under practical farming conditions, for each orchard is made up of a group of trees with root systems of various extent growing in soil of various textures. Distribution of water over the orchards is far from uniform even under the most favorable conditions. Traffic through the orchards has compacted parts of the soil, and there are extreme variations in rates of absorption of water.

PLOW SOLE, OR COMPACTED SOIL, IN MATURE ORCHARDS

The problem of distributing water uniformly to a block of orchard trees is complicated by variations in absorption rates. Even though

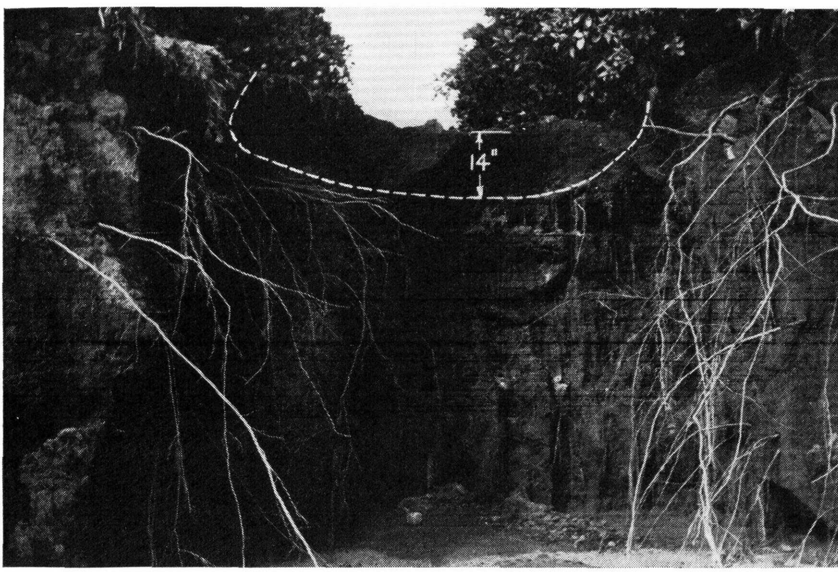

FIGURE 9.—Soil profile in a Valencia orange orchard showing compaction in a traffic lane midway between tree rows.

the soil may be of fairly uniform consistence when the trees are set out, cultivation and traffic through the orchard alter its ability to absorb water. When the soil is dry, it can sustain relatively heavy loads and may be cultivated without damage, but movement of tools and vehicles over wet soil compresses it. The compacted soil just below the depth of cultivation is commonly referred to as plow sole. Continued cultivation and traffic finally develop a compacted layer below the depth of cultivation strong enough to sustain the loads the soil is required to bear. Some parts of the soil are affected more than others. In mature orchards traffic tends to be centered midway between tree rows, and the compacted layer of soil may be dense enough to inhibit root growth. This is illustrated in figure 9, which shows the layer to be most compact in the area between trees, where most of the furrows are ordinarily located. The rate at which water percolates downward into the root zone is affected by the density and thickness of this compacted layer. Furrows in the plow-sole area may

absorb water only one-third as fast as those where the soil has not been compacted. A study was made to determine the depth to which soils in citrus orchards have been compacted and the general extent of the compacted soil.

A measure of density was obtained by recording the energy necessary to drive a standard sampling tube into the soil. The density of the compacted zone was compared with the density of undisturbed soil under the spread of the tree within 3 feet of the trunk. In mature citrus orchards the soil along the tree line close to the trunk is seldom reached by cultivating tools and has no traffic over it. Hence, tests in that area were used as control holes and served as a basis for measuring the relative compactness of the soil that was cultivated and had to bear traffic.

A summary of the results of tests made in February and March 1937 is given in figure 10. The numbers in the horizontally shaded areas indicate the number of blows from a 10-pound hammer required to drive a sampling tube three-tenths of a foot downward into the soil

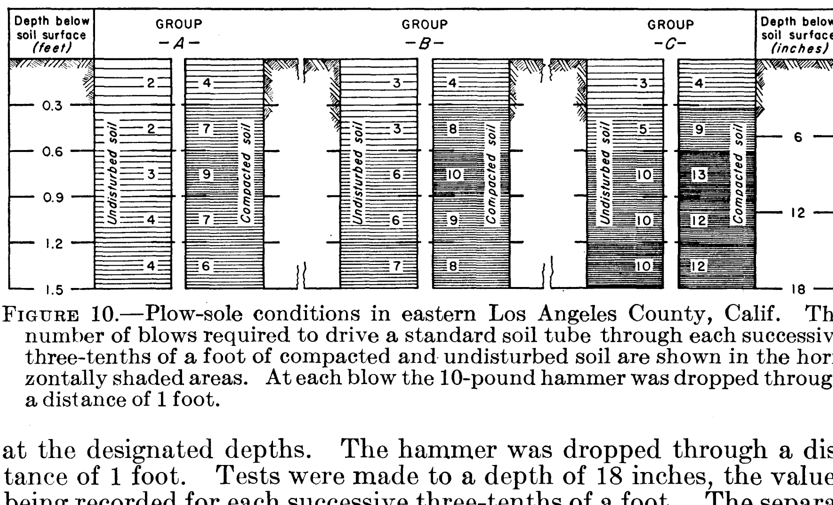

FIGURE 10.—Plow-sole conditions in eastern Los Angeles County, Calif. The number of blows required to drive a standard soil tube through each successive three-tenths of a foot of compacted and undisturbed soil are shown in the horizontally shaded areas. At each blow the 10-pound hammer was dropped through a distance of 1 foot.

at the designated depths. The hammer was dropped through a distance of 1 foot. Tests were made to a depth of 18 inches, the values being recorded for each successive three-tenths of a foot. The separation into groups *A*, *B*, and *C* was made on the basis of the consistence of the undisturbed soil at the control stations. Group *A* represents tests in loose friable soils; group *B* is intermediate between *A* and *C*, and group *C* represents tests in firm, compact soils.

The softer soils, in group *A*, which were the least stable originally, have been altered more at greater depth than the soils in groups *B* and *C*, but all have been compacted to a noticeable degree.

Over 3,500 tests were made in 52 orchards, and the soil was found to be compacted to varying degrees in all orchards. It is evident from figures 9 and 10 that compaction extends to a considerable depth. The greatest degree of compaction was found at a depth of 7 to 11 inches below the soil surface, but some was noted at 18 inches. Cultivation of the soil too soon after irrigation is responsible for much of the plow sole, but compaction at the lower depths was most probably due to the movement of heavily loaded vehicles through the orchards. In orchards on sandy soils, where compaction extended to depths of 18

inches or more, vibration from heavy tractors appears to have contributed to this condition.

Because of the depth of the plow sole, the most practical way to improve conditions is to use cover crops that send their roots down through the compacted layer. Organic matter applied as manure, while helpful in improving the physical condition of the topsoil, is not as beneficial as a well-rooted cover crop for correcting plow sole. Cultivation should always be deferred until the soil is relatively dry, and heavy traffic should be reduced to a minimum and confined to definite lanes.

Too many farmers permit heavily loaded manure trucks in their orchards when the soil is wet from winter rains. Dairy manure is often purchased at a stated price "spread in the orchard," and the damage to the soil structure caused by spreading the manure when the soil is wet may outweigh the benefits from the manure. Organic matter in the soil makes conditions favorable for the activity of beneficial soil organisms and helps to maintain the soil in good physical condition to absorb water. Careful managers will not permit these benefits to be offset by unnecessary traffic over moist soil.

ABSORPTION RATES

Compaction interferes with and restricts the downward movement of moisture. Variations in rates of infiltration of water comparable with the variations in compaction are shown in the measurements of water absorption reported in the following pages.

Many growers who have planted orchards on new lands have observed a lessening of the ability of the soil to absorb water after it has been farmed for a number of years. At first a flow of water for irrigation must be divided among only a few furrows, but as the orchard matures the same flow must be divided between a much greater number of furrows because rates of absorption have decreased. The greatest decreases have been within the plow sole or compacted parts of the soil. As the trees increase in size, traffic tends to center midway between tree rows; and when furrows are placed under the spread of the branches, the inside or tree furrows absorb water much faster than the furrows in the center traffic lanes.

Measurements were made in 16 orchards in 1936 to obtain an indication of the extent of the variations in absorption rates in different furrows. Small calibrated V-notch weirs were set in the furrows at various points, and the absorption of water along the furrows between weirs was ascertained. The necessary calculations were then made to convert the readings into equivalent inches of depth over the area served by each furrow. A sample of results is given in figure 11. A study of this figure indicates why the average efficiency of furrow irrigation may be relatively low. Extreme variations in absorption rates were found in all orchards where the tests were made. It is difficult to secure a uniform wetting of the soil where infiltration rates are so varied. If water is not to be wasted in overirrigation it is possible to demonstrate that penetration is adequate only by frequent tests with a probe or a soil tube. Because of the labor required to make these tests, however, few orchards are checked in this manner. It is much easier to apply more water for a longer time until a few

general tests show that penetration has been good. When this is done, more water is applied to some parts of the orchards than is required. Overirrigation may cause harmful effects if there is leaching caused by the application of excessive amounts of water, and yields may decrease. Even though the excess of water may not be sufficient to affect yields adversely the use of more water than is required is not good practice.

High yields in orchards where irrigation is below average and low yields in orchards where irrigation is above average, together with wide variation in yield within each irrigation group (fig. 6), suggest that in some orchards the water applied is not being utilized to the best advantage. In some orchards using 24 to 28 inches of water, for example, the yield was 7 field boxes per tree; in others, 2 boxes. Some growers have obtained good production with sparing amounts of water, yields as high as 6 field boxes per tree having been obtained with irrigation of 16 to 20 inches. Others using as much as 32 to 36 inches have had yields as low as 3 field boxes per tree.

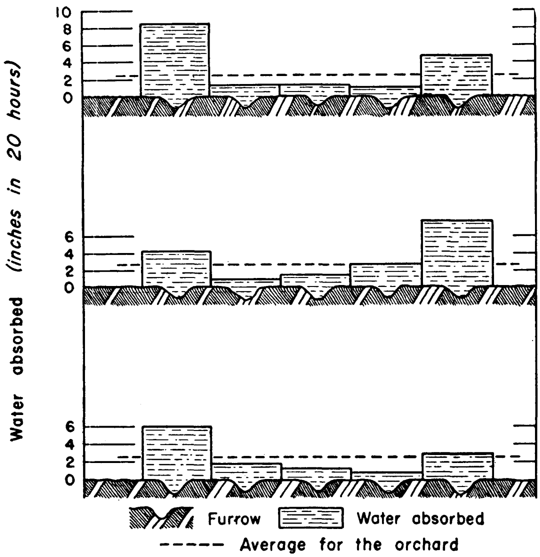

FIGURE 11.—Absorption of water from furrows in three different orchards. The inside, or tree furrows, which have absorbed the most water, are those at the right and left.

These differences may in part be attributed to differences in the effectiveness of the distribution of water in these orchards. Overcoming variations in absorption requires that the irrigator be skillful in handling the water. Even distribution of water is not achieved simply by running water in all furrows for long periods of time. On the other hand, in an orchard in which the amount of water supplied is relatively low, it is inevitable that parts of the soil will get too dry from time to time, and production may be reduced. One of the most important opportunities for advancement in present practice lies in improving the distribution of water over the orchard.

FRUIT SIZES AND IRREGULAR DISTRIBUTION OF WATER

Because the water supply varies in different parts of each orchard it might be expected that corresponding variations would be found in production. Data bearing on this question are difficult to obtain because production records are not ordinarily kept for individual trees and the fruit on a tree is not all picked at one time. Determining whether the size of fruit at harvesttime had been affected by variation in irrigation practices proved to be a feasible method of comparing production and the amount of water applied.

In the discussion of transpiration requirements and climate it was noted that winter rains usually leave the soil filled to field capacity at the end of the rainy season. The trees have this reserve supply of moisture to draw on during the spring and early summer, and shortages because of poor irrigation practices are usually not severe until late summer. Except on very light soils, most growers are able to avoid serious water shortages during the fruit-setting period. Under present practices the most severe water deficits occur in August and September. (See table 2.) Therefore, it would seem reasonable to expect that after the crop has set, the effects of poor irrigation during the season will be reflected in fruit sizes at harvesttime.

Records were obtained during the orange harvest season of 1936, and measurements of the size of 10 fruits produced on each tree were made in certain orchards. The measurements were averaged and

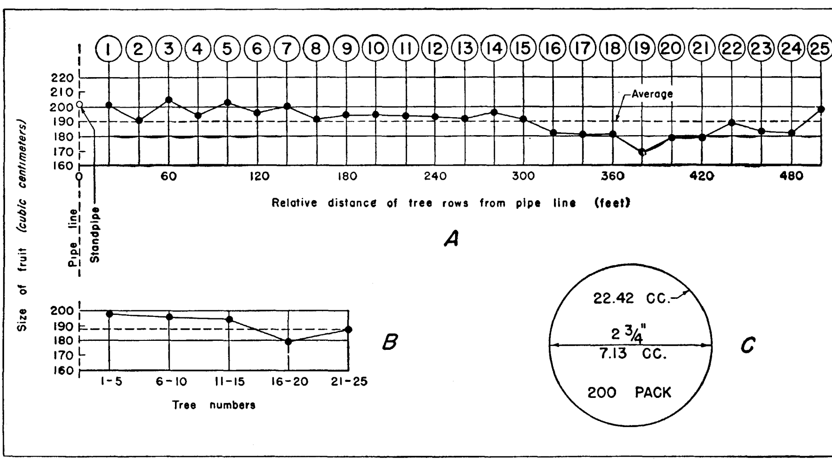

FIGURE 12.—*A*, Variation of fruit sizes along the pipe line in an orchard at Pomona, Calif., 1936 harvest. The average size of fruit and the distance from the pipe line of each row of trees (1 to 25) running east and west is indicated. *B*, The averages in *A* combined in five groups. *C*, Average size of fruit.

plotted to scale, and the plotted records were examined to determine which sections of the orchard produced fruit above or below the average size. Each row of trees was examined particularly for evidence of decreasing size of fruit as distance from the pipe line increased. Records were obtained and analyzed in this manner for over 25,000 trees in 35 orchards in the eastern part of Los Angeles County. There were 17 navel orange orchards and 18 Valencia orange orchards in the study, and a total of 256,780 fruits were measured. A summary chart of the records from one of the orchards is given in figure 12. The furrows are a little more than 500 feet long in this orchard, and fruit sizes were found to decrease as distance from pipe line increased until a point was reached 380 feet from the pipe line. The last 6 trees in this orchard were cross-blocked so that extra water was ponded along the tree lines. The effect of this added water appears in the size of the fruit on the end trees.

Many of the orchards had two or more pipe lines, and each block of trees served by a separate line was considered as a separate unit.

Thus, 60 blocks were examined, and in 38 blocks no consistent decrease in sizes away from pipe lines could be detected. In the remaining 22 blocks, or slightly less than 37 percent of the total number, the fruit sizes decreased somewhat as distance from pipe line increased. In table 3 is given the length of furrows and the percentage decrease in size of fruit along the rows in these blocks. Either more pipe lines or better methods of distributing water along the tree rows are needed in some of these orchards.

TABLE 3.—*Length of irrigation furrows and percentage decrease in fruit sizes along tree rows in 22 orange orchards in eastern Los Angeles County, Calif., irrigation season of 1935, fruit picked in spring of 1936*

Orchard No.	Soil texture	Length of furrows	Trees in row	Decrease in fruit sizes along tree rows	Remarks
		Feet	*Number*	*Percent*	
1	Gravelly sandy loam	270	13	5.3	Cross furrows at every tree.
2	do	291	14	4.1	Do.
3	Sandy loam	313	15	8.5	Do.
4	Gravelly sandy loam	486	25	12.6	Cross blocks last five trees.
5	Sandy loam	446	21	9.3	Cross blocks lower end.
6	Fine sandy loam	306	16	16.8	Do.
7	Sandy loam	276	14	4.3	Cross blocks last six trees.
8	Gravelly sandy loam	226	12	22.6	Straight furrows; no blocks.
9	do	246	13	6.0	Do.
10	Loam	325	17	9.8	Cross blocks lower end.
11	Clay loam	182	9	3.6	Straight furrows; no blocks.
12	do	225	11	11.4	Do.
13	Sandy loam	294	14	4.8	Cross blocks last six trees.
14	do	269	13	8.4	Do.
15	Gravelly clay loam	225	11	2.3	Cross blocks last four trees.
16	Sandy loam	360	18	4.7	Cross blocks at every tree.
17	Gravelly clay loam	444	23	5.8	Straight furrows; no blocks.
18	do	365	19	5.3	Do.
19	Gravelly sandy loam	946	40	6.5	Cross blocks at lower end.
20	do	204	10	8.1	Do.
21	Gravelly loam	402	19	3.9	Cross blocks last three trees.
22	Sandy loam	204	10	9.4	Straight furrows; no blocks.

In the majority of the orchards, however, the average size of fruit did not vary significantly along the rows away from pipe lines. Apparently variations in water supply were not great enough to cause measurable differences in sizes. Hence, the addition of more pipe lines in these orchards to decrease the length of furrows is not justified from this evidence alone. It appears that rather large differences in irrigation practices may exist without causing measurable differences in fruit sizes. However, the argument might be advanced that since reasonably uniform sizes are obtained, despite the present irregular distribution of water, savings in water can be effected by irrigation methods that permit a more even distribution throughout the orchard. Then deep percolation losses might be avoided and the average use of water lowered.

Figure 5 indicates that the highest production was obtained from some orchards on which the amount of water applied was considerably less than the average for the district. That fact, together with the information obtained relative to length of furrows and fruit sizes, indicates that in this area where the quality of irrigation water is exceptionally good and there is ample winter rainfall trees will maintain good production as long as the net transpiration requirements are satisfied. Where more saline waters are used some additional

water must be applied for the purpose of leaching away undesirable salts. Under present conditions in this area excess waters now applied may be saved if practical means are available for obtaining a more uniform distribution of water throughout the orchards. Relative advantages of different methods are discussed in later paragraphs.

IMPROVED IRRIGATION PRACTICES

WATER AND SOIL LOSS FROM DEEP, NARROW FURROWS

With the usual system of straight-furrow irrigation in orchards, a strip of soil along the tree line is left unirrigated. After moisture from spring rains is used, the part of the root system in this strip remains inactive until rains occur during the following winter. When attempts are made to reduce the width of this unirrigated strip, furrows may be placed so close to the trunks of the trees that lateral roots may be injured or cut off entirely by implements. Both disk blades and the common type of furrowing shovel are objectionable for this reason. Many citrus trees when pulled have shown that the main lateral roots had been seriously injured by tillage implements. Where old roots had been severed, only a few rootlets had grown out to replace them. After an old root is cut, new growth does not develop with the same vigor that characterizes new shoots after pruning.

In order to reach more of the soil along the tree lines, cross-furrows are sometimes used where the slope of the land is favorable, but this entails added labor and expense. The straight-furrow system is used more widely. Therefore, in investigations of orchard irrigation problems conducted by the Division of Irrigation special study has been made of straight-furrow irrigation methods.

The origin of the furrow method of irrigation is somewhat obscure. This method probably developed from the use of the plow for making furrows. From this start with the plow there has been a gradual development in furrowing machinery. Tools in common use are shovels or disk blades attached to carrier frames by means of standards or shanks. These implements make furrows that are relatively narrow and deep, and a number of objections to them may be cited. If water is flushed through the furrows when it is first turned on, there is an excessive movement of loose material along the bottoms of the furrows. Flow of water through narrow, sharp furrows is usually made turbulent by rocks and small clods, and with a turbulent flow more erosion occurs. There is undercutting of the sides of the furrows, and eroded material that falls into the water is carried away (fig. 13).

In a deep, narrow channel, the load carried by the water is generally not deposited until it reaches the end of the furrow, and there is a loss of valuable topsoil from the orchard. Erosion may be reduced if the rate of flow is cut down, but water then advances down the furrows very slowly. When the surface soil is air dry, wick action draws away considerable quantities of water on both sides of the slowly advancing stream. So much time is consumed before the water reaches the ends of furrows that absorption and penetration near the upper ends are much greater than farther along the furrows. A large amount of water is lost by deep percolation near the upper ends of furrows.

WIDE, FLAT-BOTTOMED FURROWS

The use of narrow furrows has persisted, although early workers recognized that wide furrows allow better penetration of water than narrow ones. The early experiments in irrigation, however, were interpreted as indicating that deep furrows and a loose surface mulch were essential in order to avoid excessive losses by evaporation. At that time it was believed that there was an upward flow of moisture that could be broken by cultivation. In 1915, however, it was demonstrated that, in the absence of a water table, the upward movement of water was very limited. This demonstration and further similar work proved that the idea behind cultivation for the purpose of conserving moisture was false. Stirring of the topsoil was shown to have no influence on evaporation losses, and therefore cultivation could be limited to that necessary for the control of weeds. In the light of present knowledge, it is clear that orchard soils should be disturbed as little as possible.

FIGURE 13.—Turbulent flow is undercutting the sides of this narrow furrow.

For many years the value of wide furrows was lost sight of because of the belief that deep and thorough cultivation was necessary. Broad furrows were used to some extent, however, in the sandy soils south and east of Ontario, Calif., about 1920, and later in Ventura County, near Oxnard. When made in sand, deep furrows tend to "sugar down" while the water is running, and after a short time a fairly wide base develops in the furrows. This led to the practice of making broad furrows. V-crowders made from 2-inch planks were used to form them. Elsewhere efforts have been made to perform the necessary orchard tillage operations with a minimum disturbance of the soil.

Work in the Division of Irrigation was directed at first toward adaptation of the shank-type implements that were in most general use. Side slopes of furrows were reduced, and a method for control of weeds in permanent furrows was worked out and has since been used in a number of commercial orchards. Permanent furrows were kept clear of weeds by the use of furrowing sweeps (fig. 14), which were drawn through the furrows. The soil is disturbed very little by these sweeps, but if weeds are to be cut satisfactorily they must not be permitted to grow for more than one irrigation interval in many situations. Frequent cultivation for weed control leaves loose soil in the bottoms of these furrows, and there is a tendency for this soil to be carried to the lower ends of the irrigation runs. Means of overcoming this movement were sought, and tests were made with

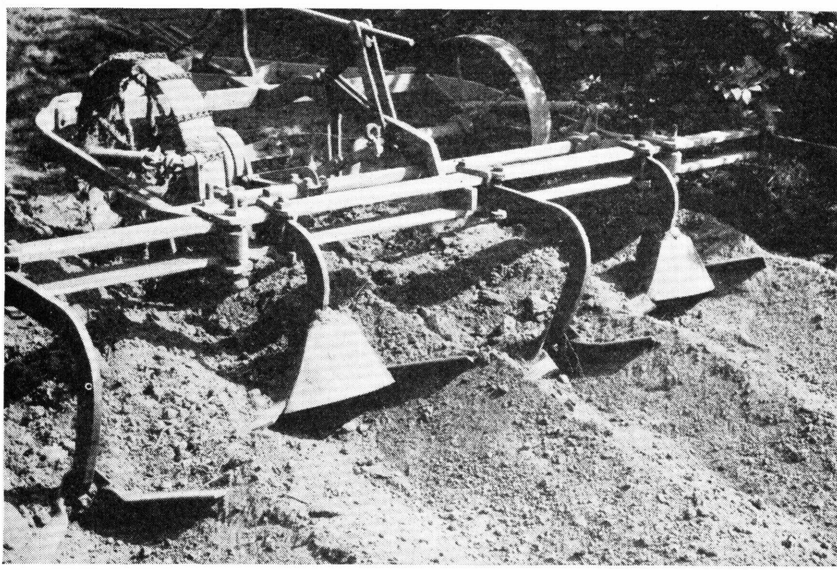

FIGURE 14.—Furrowing sweeps used for control of weeds in permanent furrows.

wide, flat-bottomed furrows in order to determine the extent to which they could be adapted for general use. Furrows of this type are illustrated in figure 15.

Equipment for Making Broad Furrows

Equipment for making broad, shallow furrows is shown in figure 16. The essential features in figure 16, *D*, are the curved blades set at the proper angle to pick up a shallow layer of soil and move it sidewise, thereby making the parallel ridges that border intervening broad, shallow furrows. The cutting edges of the blades normally run about 2 inches below the average ground surface, and the cutting depth may be even less if the orchard is properly leveled to an even grade. Thus the necessary working depth of these tools is considerably less than that required for cutting under the winter crop with a disk harrow, and, with this advantage gained, furrows can be made closer to the trees with less danger of disturbing roots.

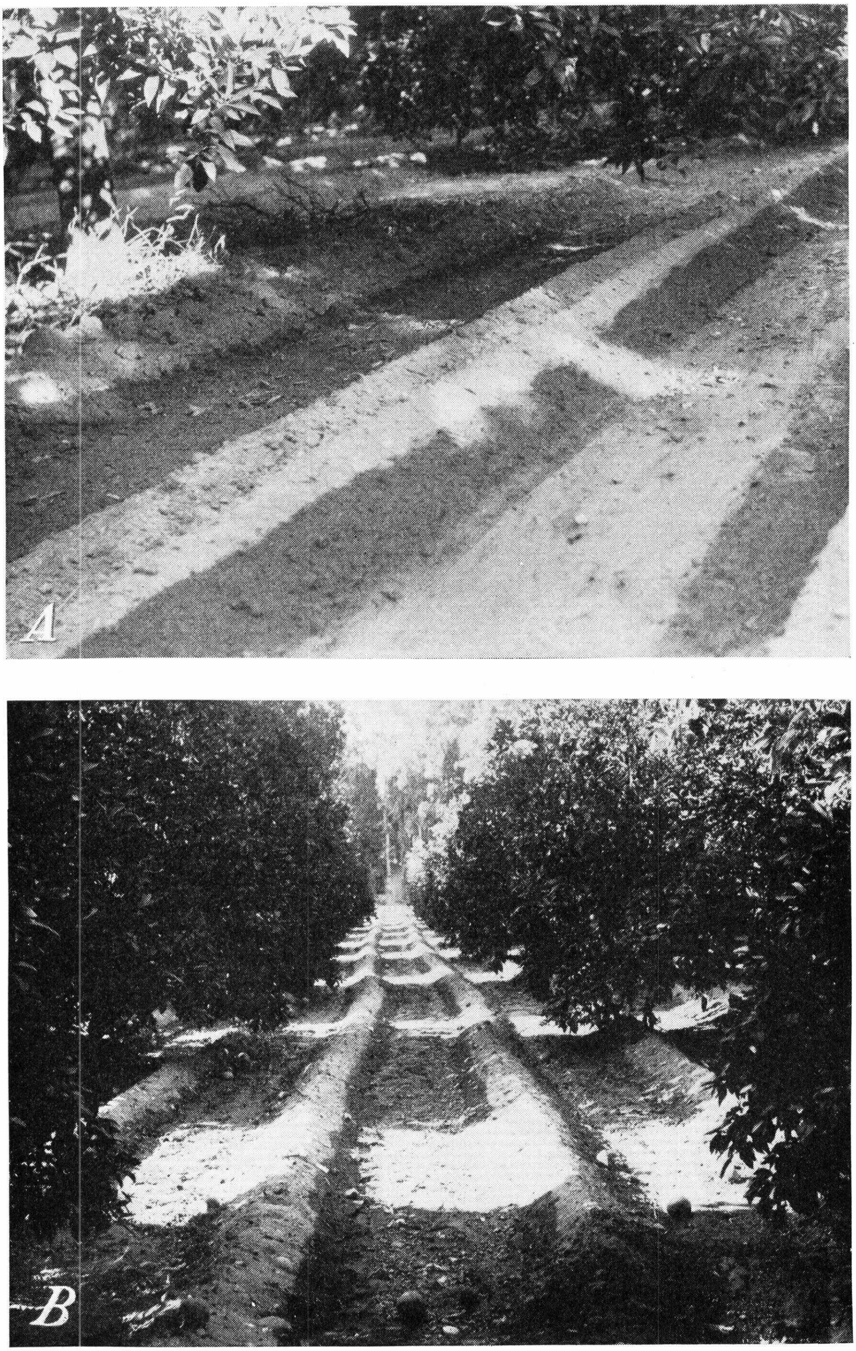

FIGURE 15.—Wetted outlines in broad, shallow furrows. These shallow furrows may be placed close to the trees: *A*, Looking across the furrows toward a single tree; *B*, looking down the furrows between tree rows.

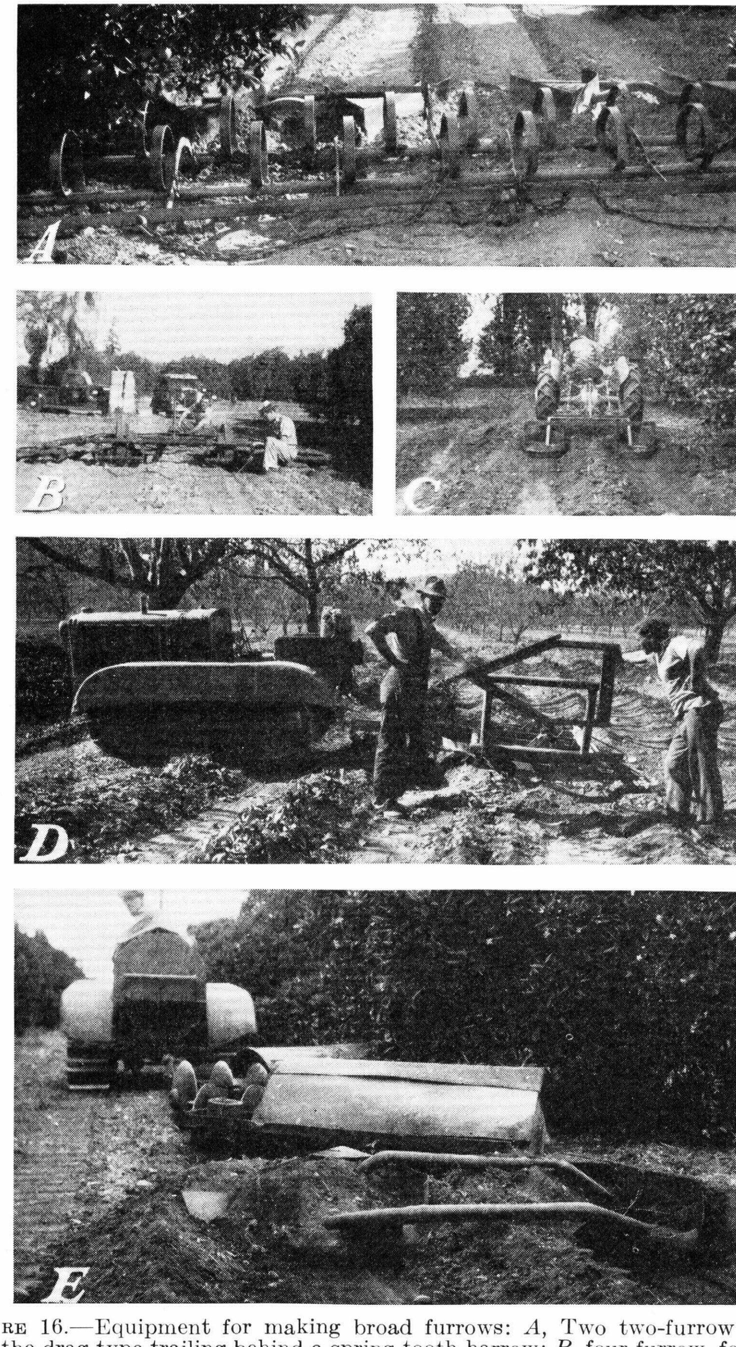

FIGURE 16.—Equipment for making broad furrows: *A*, Two two-furrow units of the drag type trailing behind a spring-tooth harrow; *B*, four-furrow, folding-wing unit with hydraulic depth control; *C*, two-furrow unit with hydraulic depth control on tractor; *D*, folding wing lifted to show blade design; *E*, low-cost two-furrow unit of the drag type trailing behind an offset disk harrow.

Cost of Broad-furrow Equipment

For a small orchard the investment for broad-furrow equipment such as that shown in figure 16, *A*, need not be more than $35. Cost of operation for four cultivations and refurrowings during the season need not be more than $4 an acre where only one trip per row is required for cultivating and furrowing, as shown in figure 16, *A*. If the spring disking costs $2 an acre, the total cost of a year's operation for cultivating and furrowing need not be more than $6 an acre. Operation costs are less where orchards have been laid out in uniform blocks and proper space has been allotted for turning at the ends of rows. In some orchards, the spring disking and necessary cultivations and refurrowings have been carried out with operation costs as low as $4 an acre a year. The average cost for the industry as a whole has been much higher. In some orchards operation costs can be reduced when the broad-furrow method of cultivation is adopted.

Along with economies in cash costs of operation, there are other savings that result from improved methods. Those who make the best use of their soil will disturb it the least and use its fertility to the maximum advantage. They will also maintain adequate moisture in the root zone and spread water evenly over the orchard without unnecessary leaching.

Cultivation Practices

The types of broad-furrow equipment illustrated in figure 16 have all been designed to perform the necessary furrowing operations with the least possible working depth. The depth of the soil disturbed need not be greater than 2 inches if cultivation with cover-crop disks is also kept as shallow as possible. In general, permitting weed growth to mature during the summer is questionable practice, although it may sometimes be necessary. Whatever gain there may be in organic matter tends to be offset by the disking operations, which prevent roots from growing into the disturbed soil. After the winter cover crop has been turned under, weeds should be kept under control so that further heavy disking is unnecessary. Depth of summer and fall cultivations should not be greater than that required for furrowing tools, which need not be more than 2 inches if broad-furrow equipment is used.

Advantages of Broad Furrows

With adequate equipment available for making broad, shallow furrows, use can be made of orchard cultivation and irrigation practices that permit more effective use of water and protect the soil from excessive erosion. Instead of gouging a deep, narrow furrow into the root zone, an effective water-conducting channel is made with the disturbance of soil (fig. 17) to a minimum depth. More nutrients from the fertile topsoil can be made available for the roots. Water spread over more of the soil surface is more effective in moving soluble plant nutrients into the root zone.

Flow along the smooth, wide furrows is less turbulent, and water may be conducted to the lower ends of the furrows in less time and with less erosion. Fewer furrows are required, and hence less labor is needed for regulating the flow. Repeated irrigations may be applied in the same wide furrows with less clogging from leaves and trash. Cover crops can be started more readily, because it is easier to keep

more of the topsoil moist, and effective light irrigations can be applied. The cover grows in the bottoms of the furrows, where it is more effective in retarding erosion and improving penetration.

When it is necessary to leach out toxic accumulations of salts, broad furrows are advantageous. Plants extract the water from the soil solution and leave much of the salt residue to accumulate within the root zone. If this salt residue is not washed downward by rain, removal by irrigation may become necessary. With wide furrows there is less tendency for a building up of salts midway between furrows. By alternating the position of furrows and ridges at sub-

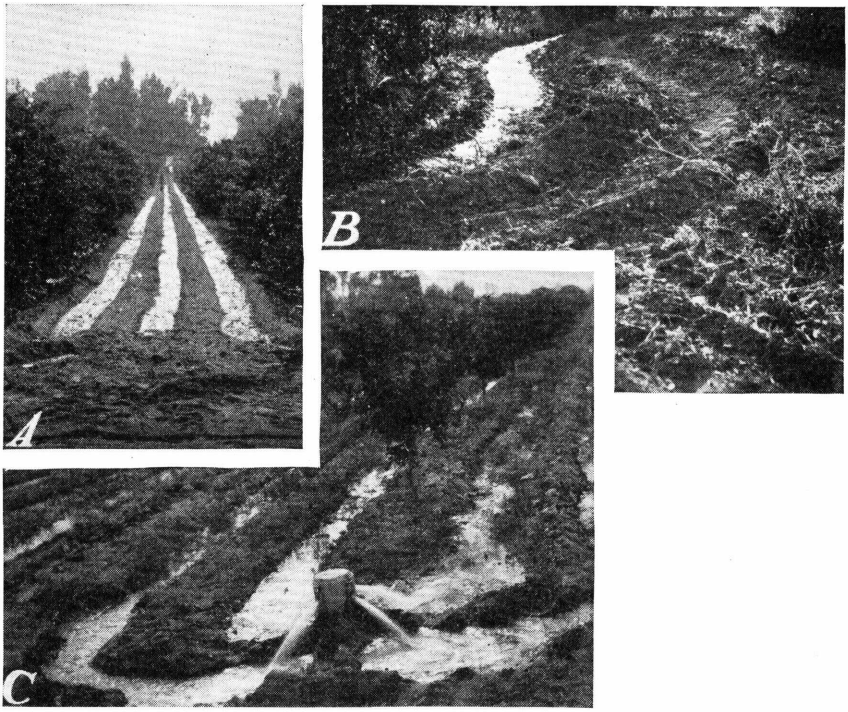

FIGURE 17.—Broad-furrow irrigation: *A*, In an orchard where there is no cross slope; *B*, On a contour planting where the soil is heavy and the grade steep; *C*, in an orchard on coarse stony soil.

sequent irrigations, effective leaching can be accomplished and injurious salts washed out. However, when injurious salts must be leached, it should be remembered that soluble plant nutrients go also, and it may be necessary to add nitrates after a thorough leaching.

Thus, there are many advantages in using broad, shallow furrows. Growers who have tried this method have found it to be an improvement over old methods and have continued its use. The best water distribution is obtained with broad furrows on land with little or no cross slope. When the land has considerable cross slope, water tends to run against the downhill side of the furrows so that the entire furrow bottom may not be covered with water. Nevertheless, broad-furrow machines have been used in contour furrowing on hillsides,

and the furrows proved advantageous because of shallower cultivation, less choking from weeds, less breaking-over, and better cover crops.

Change to Broad-Furrow Irrigation

Irrigators find that water must be handled in a somewhat different manner in broad furrows and in narrow ones. A larger flow is used in each furrow, and water reaches the ends of broad furrows in less time. It is absorbed at higher rates since there is more water in contact with soil and the time required for each set is, therefore, less. With proper adjustment, water reaches the lower ends of broad furrows in a very thin sheet, and hence its velocity at the lower end is very low. Some study is required with the broad-furrow system if full advantages are to be secured. When making changes in irrigation practices, growers will find it profitable to check on soil moisture and fruit growth. (See pp. 10–11.)

FIGURE 18.—The ridge of soil in the center of the stream directs part of the water from this broad furrow into the furrow next to the trees.

In many orchards soil-moisture control has been tried where the irrigation methods were so erratic that the attempted control was of doubtful value. It is usually essential to correct the manner of water distribution before attempting to control moisture. Methods for soil-moisture control and for determining the best irrigation interval can then be used to advantage.

DISTRIBUTION OF WATER

The problem of distributing water in furrows requires that special attention be given furrows next to the trees. Tree furrows usually absorb water readily, and many growers equalize the distribution along the orchard row by diverting water from center furrows into tree furrows at one or more points along the row. This is usually done where broad furrows are used on extra-long runs. A convenient

method of making these diversions is illustrated in figure 18. A long ridge of soil juts out into the center of the stream to be divided, and the division holds its set because the water is turned gradually and its velocity is not checked. Abrupt turn-outs or divisions from furrows usually fail quickly either because of the silting-up of one side or the other or because of the cutting-away of the soil on one side of the division point. Where small gravel is available, it can be used to advantage in making divisions. It is of considerable help where the water must be taken from the pipe line through one gate and then divided among several furrows. Many irrigators keep a small supply of pea gravel at the head of each row.

CARE OF YOUNG TREES

For the most profitable management of mature orchards it is usually necessary to adopt a program for replacing weak, diseased, or unprofitable trees. The care of young trees replanted in mature orchards is a special problem. Young replants cannot develop properly under the irrigation and cultivation schedule on which the large trees are maintained. A certain amount of extra hand labor is required around each replant for several years after it has been set out. Because more sunlight reaches the area around small trees, weeds grow rapidly and soon offer serious competition for fertilizer and water. Weeds should be hoed down until the trees develop sufficiently to shade out the growth around the trunks of the trees. The winter cover crop should be watched carefully in late February and March, and hand work around the young trees should be started before the regular spring cover-crop disking. The small trees should be given every opportunity to push out during the spring flush of growth, when growing conditions are most favorable.

For the irrigation of small trees, basins may be employed for 2 or 3 years. Water is carried to the young trees in tank wagons during the first year, and after that definite amounts of water may be turned in from adjacent furrows. Basins or short lengths of extra furrows should be made so that water does not stand around the trunks of the trees in order to lessen the danger of infections from brown rot gummosis. If water is left too long around the young trees, all the soluble plant nutrients will be washed down beyond the reach of their roots. Broad furrows are especially useful for applying frequent light irrigations around the young trees.

CROSS-BLOCKING FURROWS

As illustrated in figure 12, cross-blocking of the furrows at the lower ends of long rows improved fruit sizes on the trees near the ends of the rows. So long as care is taken to avoid ponding too much water, cross-blocking at the lower end may be used to take care of minor fluctuations in flow. Then run-off from some furrows and drying back of others may be prevented. Some soils take water slowly, and water must be kept in furrows for 12 hours or more. There is then a problem of fluctuations in rate of entry of water into the soil throughout the day owing to temperature changes and an evaporation effect. In some tests made at Pomona in 1937 it was found that certain furrows absorbed 10 percent more water at 2 p. m. than at 5 a. m. Water temperatures near the ends of furrows ranged

from 60° in the early morning to 95° at 2 p. m., and tests have proved that warm water is absorbed more readily than cool water. Under practical farming conditions, when the soil takes water slowly, it is necessary to allow for 10 percent run-off to take care of evaporation and the effect of temperature changes or else make continuous adjustments of the flow. Since the latter process adds to the labor cost, allowance for the run-off may be the more economical.

Cross-blocking along the tree lines at the ends of rows is practical where the cross slope of the land is negligible. Under some circumstances it is advisable to cross-block the entire orchard; for example, where so much soil has been washed away that lateral roots are at the ground surface and straight furrows cannot be made close enough to the trees for adequate irrigation. The system of cross blocking illustrated in figure 19 is similar to that used in walnut orchards.

FIGURE 19.—Orchard laid out with cross furrows along the tree lines. Cross connections had not been made when this picture was taken.

If the orchard is laid out in this manner, cross furrows are made first; the implement with blocking attachments is then used, and the tree furrows are cross-blocked in the direction water is to flow. The irrigator directs the flow so that it zigzags back and forth along the tree line in the cross furrows. Usually the upper third of the row is irrigated with water turned in at the head of the row. Water is carried down center furrows and diverted into the cross-blocked furrows at one-third and two-thirds of the distance along the row. This lay-out leaves the two center or lead furrows available for traffic through the orchard.

The lay-out just described is also an effective method for control of winter rains. Cover crops can be started readily, since the entire surface soil can be moistened quickly with a light irrigation. How-

ever, straight furrows are in more general use, and, while cover crops can be started readily in straight furrows of the broad, shallow type, there is usually some run-off from winter rains in the center furrows because they are compacted. Run-off from the center furrows may be diverted into the tree furrows at several points along the tree rows, where it is absorbed more readily. Thus run-off from the orchard is prevented in normal rains and kept under control when rainfall is excessive. It is well to keep the furrows open and not pond too much water within the orchard during exceptionally heavy precipitation. After the root zone is thoroughly moistened, nothing is gained by waterlogging the soil with excess water. Some damage occurred in 1914 and 1916 because basins were formed and left in the orchards during those excessively wet winters. A well-established cover crop in broad furrows affords adequate protection to the soil even when there is general run-off. Figure 20 illustrates cover crops developed under cross-blocked and straight-furrow systems.

IRRIGATION WITH LOW-HEAD SPRINKLERS

On steep hillsides where erosion may be serious, portable low-head sprinklers are used to advantage. This method of irrigation is illustrated in figure 21, *A*. Portable pipe lines with quick-acting couplings are available in sizes suitable for orchard use. Three or more sprinklers may be used on each portable unit, and each sprinkler head is intended to throw water within the space cornered by four trees. The units are shifted by dragging them endwise through the orchard or by uncoupling the pipe and carrying the sections to the next set. Better distribution of water to each tree and lower cost make this system more desirable than a permanent sprinkler installation throwing water over the tops of the trees.

With the broad-furrow method of cultivation, illustrated in figure 16, *A*, it is not necessary to disturb the soil for a depth of more than 2 inches. Hence, broad furrows can be laid out in sprinkler-irrigated orchards at low cost. They control run-off both from winter rains and from the sprinklers, as is illustrated in figure 21, *B*. With broad furrows, run-off water does not travel far, for the movement of water in thin sheets is slow. If this is taken into account, the design of the sprinkler lay-out can be more economical.

ALTERNATE-MIDDLE IRRIGATION

Some hillside orchards can be farmed best with a more or less permanent cover crop that is mowed from time to time. This practice is used in the orchard shown in figure 21, *B*. Cover may be left in alternate rows. This is an economical method where summer cover crops are used since it enables the grower to keep an adequate supply of moisture for the tree in the clean-cultivated middles even though the cover may dry out on one side of the trees more or less completely. Cover crops use water, and moisture conditions must be watched more carefully when there is a cover. If water is to be applied in alternate middles the flexibility of low-head units is a definite advantage.

While alternate-middle irrigation has been used through the entire season in a few orchards, it has a more general application for irriga-

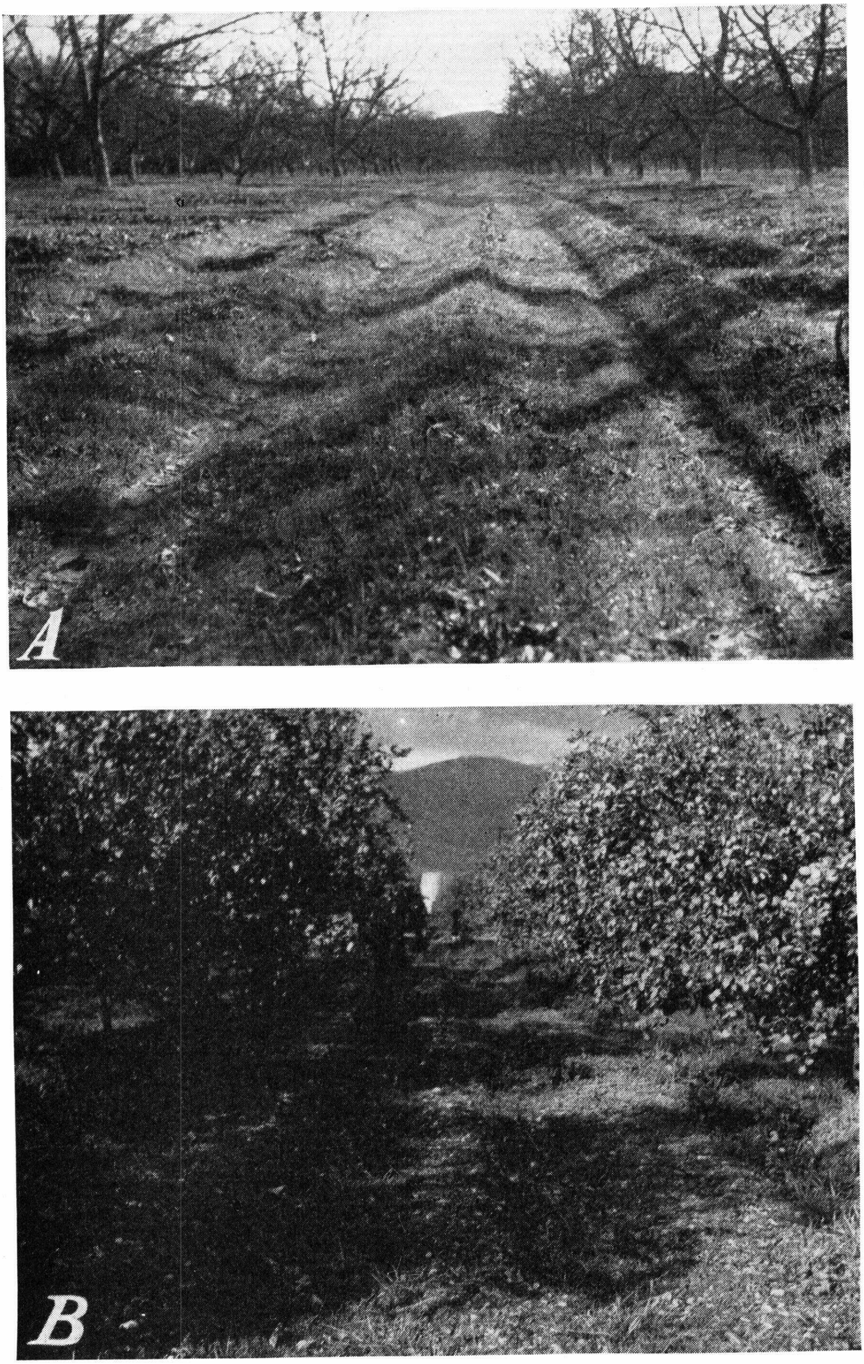

FIGURE 20.—*A*, A winter cover crop in an orchard with cross-blocked furrows. Note provision for traffic through the orchard with this lay-out. *B*, A volunteer winter cover crop in broad, shallow furrows.

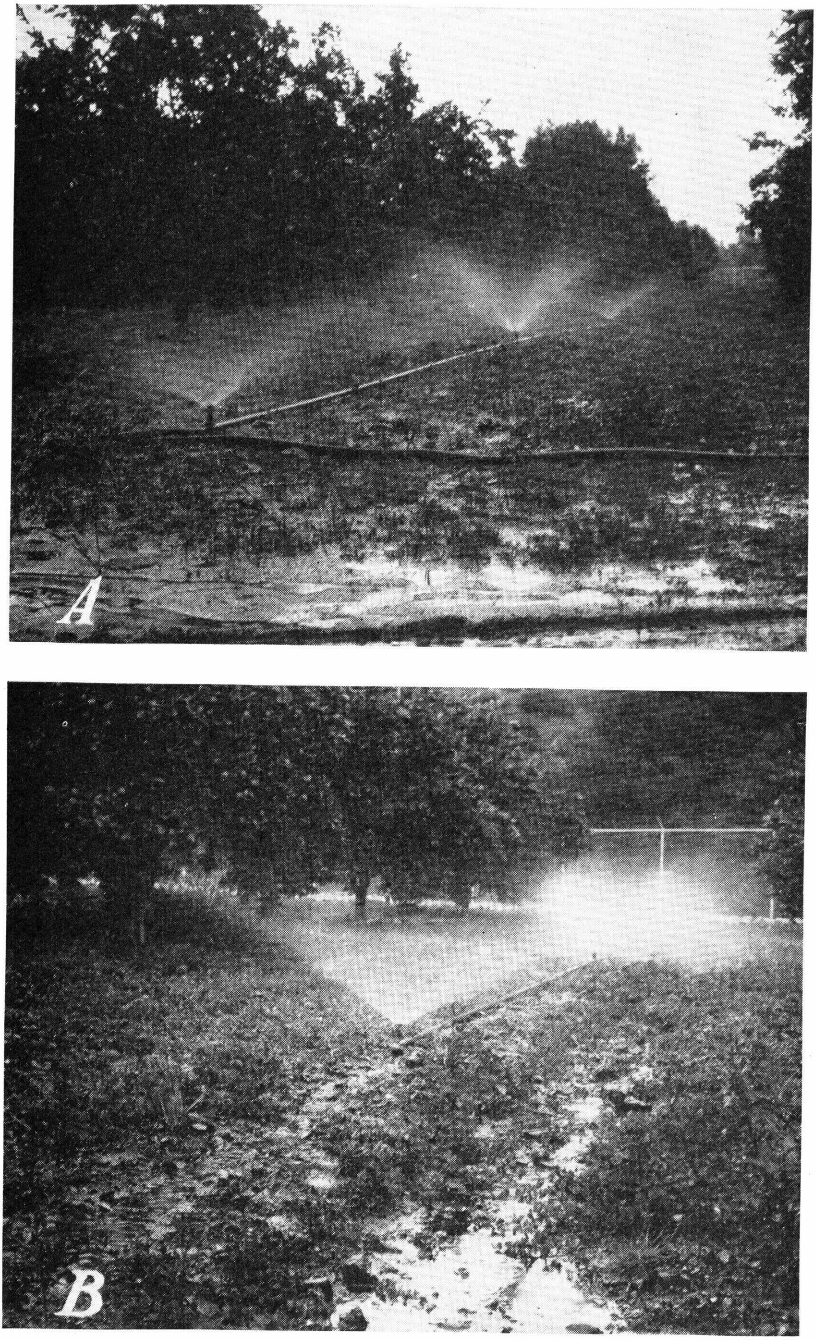

FIGURE 21.—*A*, Irrigation with portable low-head sprinklers; *B*, sprinkler-irrigated orchard with broad furrows for control of run-off.

tions that are applied during the cooler months of the year. It is not necessary to wet the entire root zone if the transpiration demand is low, when alternate-furrow or alternate-middle irrigation may be used and some economy in operation effected. Water may be applied as indicated in figure 22 so that it reaches one-half of the roots of each tree and leaves the remaining half unirrigated. Water is cross-transferred readily throughout the tree so that the entire tree will receive a supply of moisture when one-half the root zone is irrigated. While this is true of the movement of water within the tree, it should not be inferred that mineral nutrients travel in a similar manner. Nutrients from the soil appear to travel in rather definite paths from main roots to main branches; hence, when fertilizer is applied it should be broadcast on all sides of the tree.

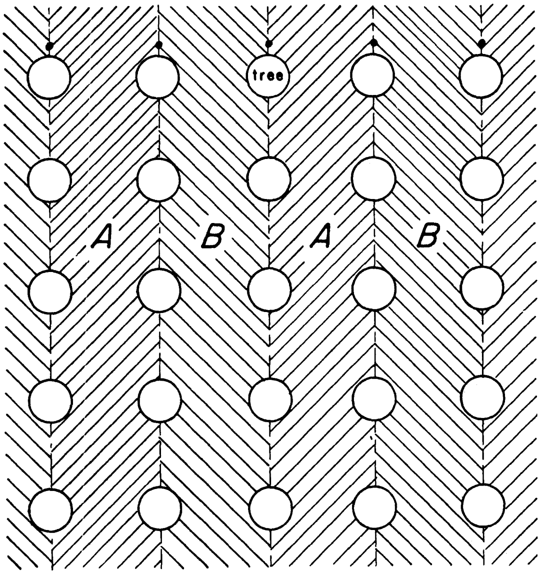

FIGURE 22.—Alternate-middle irrigation. *A* middles are irrigated while *B* middles are left dry; at the next irrigation the *B* middles are irrigated and the *A* middles left dry.

The main purpose of alternate-furrow or alternate-middle irrigation is to distribute a relatively small amount of water over the orchard to better advantage. It offers some opportunity for improving efficiency in the application of water and attaining the maximum economy in operation. The greatest opportunity for advancement over present methods appears to be in better distribution of water within the orchard. Both broad furrows and low-head sprinklers are advantageous in this respect.

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